TECHNICAL AND ECONOMIC ANALYSIS OF AN ENZYMATIC HYDROLYSIS BASED ETHANOL PLANT

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Preface

This report was prepared by the following members of the Biotechnology Research Branch of the Fuels and Chemicals Research and Engineering Division.

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Section 1.0

Summary

An analysis of the technical and economic status of the biomass-to-ethanol process was conducted for the Ethanol Program of the U.S. Department of Energy's (DOE) Biofuels System Division. The purpose was to redesign and update the process technology since the last time an analysis was performed (Wright 1988). Since that time, the process and economic parameters have been changed and redefined, significantly changing and improving the technology. The primary objective of this work was to establish goals and direction for future research for the production of ethanol from lignocellulosic biomass.

An economic analysis is performed on a fuel ethanol (90% ethanol, 5% water, and 5% gasoline) plant producing approximately 58 MM gal/yr. The feedstock to the plant is assumed to be whole-wood tree chips delivered to the site for $42/dry ton. The chips are stored in piles and then delivered on a first-in, first-out basis to a disk refiner for milling to 2.0-mm to 3.0-mm particles. The milled particles are pretreated with dilute acid at 160°C for 10 min. After flash cooling, the slurry is neutralized with lime and a small side stream is pumped to the cellulase production fermenters, while the rest of the stream is pumped to the xylose fermenters. Xylose fermentation is performed by a genetically engineered *Escherichia coli* continuously in a series of fermenters. Cellulase is produced by *Trichoderma reesei* in three batch fermenters. The cellulase is combined with the stream out of the last xylose fermenter, yeast inoculum is added, and simultaneous saccharification and fermentation (SSF) is performed continuously in another series of fermenters. The dilute beer stream from the last SSF fermenter is sent to ethanol purification for concentration of the ethanol to 95 wt %. Then, 5% gasoline is added to denature the fuel. The stream from the bottom of the beer column is sent to centrifugation to remove the solids, which are then burned in a boiler to produce steam and electricity for the plant. A fraction of the liquid stream from centrifugation is recycled back to the process, while the rest of the stream is sent to a wastewater treatment system.

Based on the equipment list generated from the process flow diagrams, the total capital cost for this plant in first-quarter 1990 dollars is $141.24 MM. The annual capital charge rate is 20%, giving a capital charge of 48.3¢/gal. The variable operating cost (chemicals and feedstock) is 60.1¢/gal and the fixed operating cost (labor, taxes, and insurance) is 19.8¢/gal, giving a gross cost of production of 79.8¢/gal. When by-product credits (electricity) are included, the net cost of production is 73.4¢/gal. The total cost of production for the denatured fuel is 121.7¢/gal.

To assign priority to research issues, a sensitivity analysis was performed on major process variables and assumptions. The results for some of the major technical parameters that have a significant impact on ethanol cost are shown in Figure 1-1. This sensitivity analysis varied only one parameter while holding the other parameters at their base case values. The bars show the percent deviation of ethanol cost from the base case value of 121.7¢/gal, when the indicated changes are made from the base case values shown on the bottom of the figure. Particularly evident is the effect of nutrient requirements and SSF ethanol yield on the cost of ethanol. Figure 1-2 shows the impact of some issues that are not directly related to conversion technology, such as plant size and feedstock cost. Again, all these variables have a major impact on the cost of ethanol ranging from 5% to 15% or 6¢ to 18¢/gal of ethanol. When the effects of multiple process improvement are considered, the cost of ethanol drops to 66.5¢/gal.

Based on the results of the sensitivity analysis, future work should focus on strengthening understanding of the base case process, developing and improving the technology for biomass conversion, and continually analyzing and updating the process design. Understanding the base case process will involve efforts in four major areas: in-house integration research, vendor testing, subcontracted work to

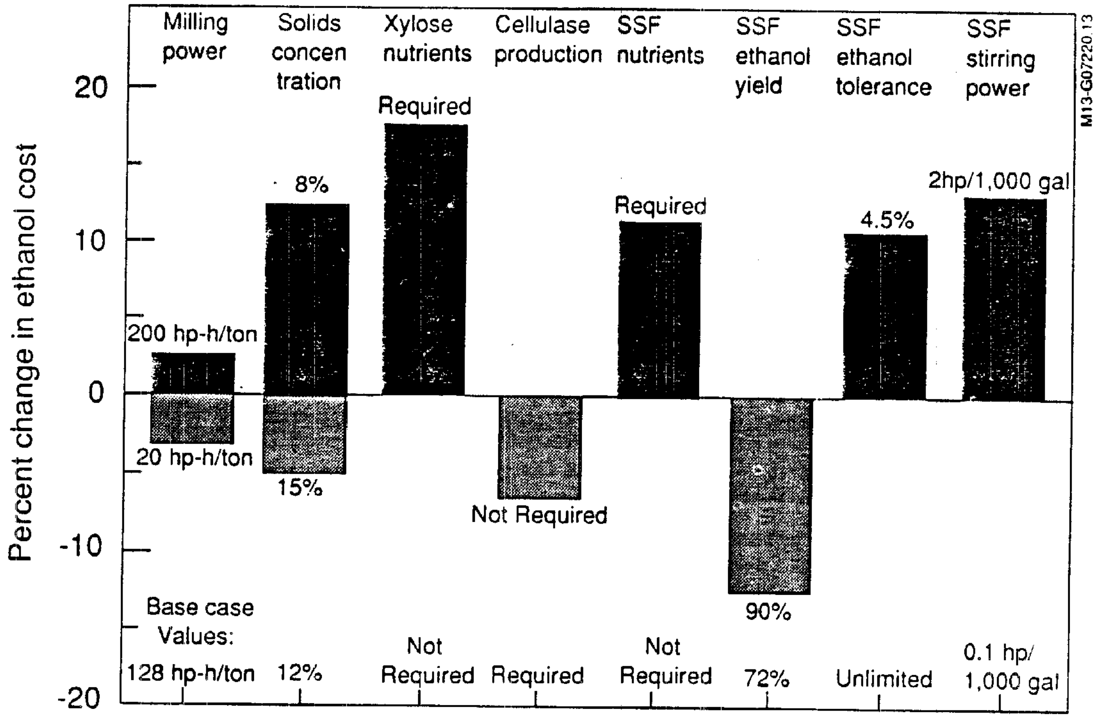

Figure 1-1. **Percent change in ethanol cost caused by deviations of major technical parameters from their base case values**

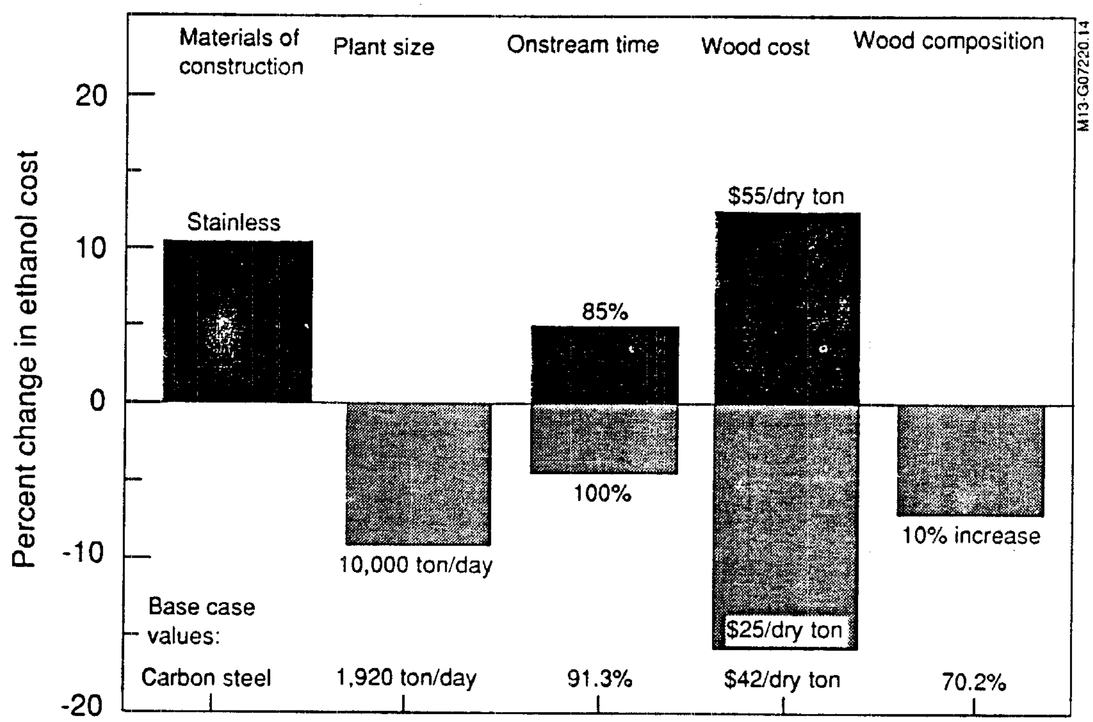

Figure 1-2. **Percent change in ethanol cost caused by deviations of major process parameters from their base case values**

engineering companies, and in-house pilot plant operations. The purpose of the integration research effort is to verify the performance of a fully chemically integrated system, which means testing the performance of pretreated feedstock and hydrolyzate from prehydrolysis through the back end of the plant as specified in the current process diagrams. Other issues should also be addressed, such as nutrient requirements, seedcultures, material balance closure, and process water recycle. Vendor testing is required to verify operation and performance data on equipment specified in the current process design. Equipment to be tested includes: mills, prehydrolysis and impregnation reactors, slurry pumps, large fermentation processes, distillation columns, lignin separation equipment, and boilers. Subcontracted work to engineering companies should examine such issues as materials of construction and waste treatment design. Pilot plant operation is required to verify the performance of the integrated process on a larger scale and to obtain information on process reliability and scale-up data for design of larger plants.

Although the primary goal of the above work is to verify the current technology, work must also progress on improving the technology. Specific areas to consider are improving ethanol yields, decreasing fermentation rates, increasing solids concentrations, eliminating or reducing seed fermentation and cellulase production requirements via recycle technology, and improving reactor designs and technologies. Because of the above tasks, periodic process analysis must also continue as new information is available in order to monitor research progress and identify areas for further research.